IN THE SPECIFICATION:

Pursuant to 37 C.F.R. §§ 1.121 and 1.125 (as amended to date) please enter the substitute specification in clean form and including paragraph numbers **[0003]**, **[0007]**, **[0009]**, **[0012]**, **[0013]**, **[0015]**, **[0029]**, **[0032] through [0036]**, **[0040]**, **[0043]**, **[0044]**, **and [0046]** and Abstract. A marked-up version to clearly identify amendments to the specification as required by 37 C.F.R. § 1.121(b)(3)(iii) is attached.

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[0003] Background of Related Art: Conventionally, metal masks were used to selectively control the application of solder balls to the contact pads through which a semiconductor device would electrically communicate with other devices external thereto. Metal masks have typically been made from molybdenum, which exhibits long-term dimensional stability at high temperature and may be reused.

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[0007] Following the deposition of solder to contact pads through a metal mask, the apertures of the metal mask must be larger than the cross-section of the solder bumps formed therethrough in order to facilitate removal and reuse of the metal solder mask. While dry film and polymeric solder masks dictate the contact location of a substrate upon which solder bumps are formed or applied, dry film and polymeric solder masks are typically very thin in order to facilitate their retention on or their removal from the substrate. Thus, the apertures of dry film and polymeric solder masks may not define the configuration of solder bumps; rather, dry film and polymeric solder masks are typically used to position spherical solder bumps on the contact pads of a substrate.

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[0009] Thin polymeric films, such as adhesive tapes, have also been applied to printed circuit boards to be used as solder masks. United States Patent 5,388,327 (hereinafter "the '327 Patent"), which issued to Trabucco on February 14, 1995, and United States Patents 5,497,938 (hereinafter "the '938 Patent") and 5,751,068 (hereinafter "the '068 Patent"), which issued to McMahon et al. on March 12, 1996, and May 12, 1998, respectively, disclose adhesive films that carry preformed conductive bumps. The conductive bumps carried by the film are aligned with

corresponding contact pads of a printed circuit board, the film is adhered to the printed circuit board, the conductive bumps are each secured to their corresponding contact pad, and the film is removed from the printed circuit board with a solvent. The use of such a carrier film is, however, somewhat undesirable since, during application of the film to the printed circuit board, air pockets may form between the film and the printed circuit board and a sufficient contact between one or more of the conductive bumps and their corresponding contact pads may not be established. Thus, the conductive bumps may not secure sufficiently to their corresponding contact pads on the printed circuit board to establish an adequate electrical connection with the contact pads. Moreover, the use of such an adhesive film to facilitate the disposal of solder bumps on a bare or minimally packaged semiconductor device is not disclosed in the '327 Patent, the '938 Patent, or the '068 Patent.

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[0012] The present invention includes a method of disposing solder bumps on a substrate, such as a bare or minimally packaged semiconductor device or a printed circuit board (e.g., the printed circuit board of a ball grid array ("BGA") package). The method of the present invention employs a solder mask comprising a dielectric film, such as a polymer, silicon oxide, glass (e.g., borophosphosilicate glass ("BPSG"), phosphosilicate glass ("PSG"), or borosilicate glass ("BSG")), or silicon nitride, with apertures formed therethrough. The present invention also includes solder masks that may be used in the inventive method, as well as semiconductor devices fabricated in accordance with the method of the present invention. As used herein, the term "solder mask" is expansive and not limiting, including structures for application of materials to substrates to form conductive elements, whether metallic or nonmetallic.

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[0013] The method of the present invention includes aligning a film of dielectric material, such as a polymer, silicon oxide, glass, or silicon nitride, with a substrate, such as a bare or minimally packaged semiconductor device or a printed circuit board. The film may be preformed or formed during disposal thereof onto the substrate. The film has apertures formed therethrough, which are substantially aligned with contact pads of the substrate, such as the bond

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pads of a bare or minimally packaged semiconductor device or the terminals of a printed circuit board, so as to expose the contact pads through the solder mask. The apertures are configured to impart a solder bump formed therein with a desired configuration. Apertures may be formed in the solder mask prior to, during, or subsequent to disposal of the solder mask on the substrate.

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[0015] When the formed conductive structures have adequately solidified, the solder mask may be substantially removed from the substrate. Depending upon the type of material employed as the solder mask, the solder mask may be removed by peeling the film from the substrate (e.g., if a polymer is used as the solder mask) by use of suitable solvents (e.g., if a polymer is used as the solder mask), by etching the film from the substrate (e.g., if a polymer, silicon oxide, glass, or silicon nitride is used as the solder mask), or otherwise, as known in the art. Alternatively, the thickness of the solder mask may be reduced to expose the sides, or peripheries, of the conductive structures. For example, if the solder mask is comprised of a polymeric material that may be shrunken when exposed to a certain chemical or chemicals, to a plasma, or to radiation, the solder mask may be shrunken to expose the sides, or peripheries, of the conductive structures formed therewith. As another example, the thickness of the solder mask may be reduced by etching the dielectric material.

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[0029] With reference to FIG. 1, a semiconductor device 10 according to the present invention, which includes a substrate 12 with integrated circuitry thereon and contact pads 14 (*see* FIGs. 2-8) in electrical communication with the integrated circuitry is illustrated. As depicted, substrate 12 is a semiconductor die and contact pads 14 are the bond pads of the semiconductor die. Typically and conventionally, the bond pads, when used with a tin/lead solder, may be coated with a plurality of superimposed metal layers to enhance the bonding of the solder to the metal of the bond pad. Further, contact pads may be offset from the bond pads and connected thereto by circuit traces extending over the active surface so as to rearrange an input/output pattern of bond pads to a pattern more suitable for an array of conductive bumps. Semiconductor device 10 also includes a solder mask 16 comprised of dielectric material disposed over an active surface 13 of substrate 12. Solder mask 16 includes apertures 18 aligned

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substantially over contact pads 14. Conductive structures 24 are disposed in apertures 18 so as to communicate electrically with their corresponding contact pads 14 exposed to apertures 18. As used herein, the term "semiconductor die" encompasses partial and full wafers as well as other nonwafer-based substrates, including by way of example only silicon on sapphire ("SOS"), silicon on glass ("SOG") and, in general, silicon on insulator ("SOI") substrates.

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[0032] As an example of the manner in which solder mask 16 may be disposed on active surface 13, a solder mask 16 comprising a film of a dielectric material with pre-formed apertures 18 therethrough may be aligned with the features of active surface 13, such as contact pads 14, and secured (e.g., by a pressure sensitive adhesive) to active surface 13. Preferably, the material from which solder mask 16 is made is a non-conductive polymer, such as a polyimide, that withstands the temperatures of the molten conductive materials, such as solders (e.g., temperatures from about 190° C. to about 260° C.) or conductive elastomers, to be disposed within apertures 18 without undergoing substantial conformational changes and without substantially degrading. Alternatively, solder mask 16 can be made of other dielectric materials, such as silicon oxide, glass (e.g., BPSG, PSG, or BSG), or silicon nitride. Apertures 18 may be preformed through the film of dielectric material by known laser ablation or laser drilling processes, by known mask and etch processes, or by other known micron-scale and submicron-scale processes for patterning the particular dielectric material employed as solder mask 16.

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[0033] Alternatively, a layer of photoimagable polymeric material, such as a photoimagable polyimide, may be disposed on active surface 13 by known processes, such as by spin-on techniques, by curtain coating, by roller coating or by use of electrostatic spray. Solder mask 16 and the apertures 18 therethrough may then be formed from the layer of photoimagable material by known photoimaging processes, thereby substantially exposing contact pads 14 to apertures 18 and through solder mask 16. Again, the photoimagable polymeric material preferably withstands the temperatures of molten conductive material (e.g., solders, metals, and metal alloys) to be disposed within apertures 18 without undergoing substantial conformational changes or substantial degradation.

[0034] As another alternative, solder mask 16 may be fabricated by disposing a layer of dielectric material, such as a nonphotoimagable polyimide, silicon oxide, glass, or silicon nitride, on active surface 13 of substrate 12 by known processes. For example, known spin-on techniques may be employed to form layers of polymeric material and glass on active surface 13. As another example, layers of polymeric material may also be disposed on active surface 13 by curtain coating, by roller coating, by use of electrostatic spray, or by screen printing, which also patterns the layer of polymeric material substantially simultaneously with disposing the polymeric material on active surface 13. Known chemical vapor deposition ("CVD") techniques may be employed to dispose a layer of silicon oxide, glass, or silicon nitride on active surface 13.

[0035] Apertures 18 may be formed through the dielectric material by known processes, such as by disposing a photomask over regions of the layer of dielectric material that are to remain on active surface 13 and by removing the dielectric material located above contact pads 14 through holes in the photomask. For example, known isotropic (e.g., wet chemical etching) and anisotropic, or dry, etch processes, such as barrel plasma etching ("BPE") and reactive ion etching ("RIE") processes, may be employed to form apertures 18 through a layer of polymeric material. Etching processes may likewise be used to form apertures 18 through silicon oxide, glass, and silicon nitride solder masks 16.

[0036] With reference to FIG. 3, a quantity of conductive material 22 is then disposed within each aperture 18 of solder mask 16. Conductive material 22 may be disposed within apertures 18 in molten or liquid form, as a powder, or as a paste. If solder, such as a tin/lead solder, is employed as conductive material 22, known processes may be employed to apply flux and the solder to the exposed surface of solder mask 16 and to dispose the solder within apertures 18. For example, known wave solder processes or solder ball disposition techniques may be employed to dispose the conductive material 22 into apertures 18. While in apertures 18, conductive material 22 is liquified, which permits conductive material 22 to substantially fill each aperture 18. As the conductive material solidifies, it bonds to the portions of contact pads

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14 exposed through apertures 18, forming conductive structures 24 that are electrically linked to each of the contact pads 14 exposed to apertures 18. The shape of each conductive structure 24 is determined by the shape of the aperture 18 in which conductive structure 24 was formed.

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[0040] Alternatively, other means of reducing the thickness of solder mask 16 may also be employed, such as shrinking a polymeric solder mask 16 with an oxygen plasma, with another type of plasma, with chemical shrinking agents, or by exposing solder mask 16 to radiation. An exemplary method of shrinking small spheres made of polystyrene, polydivinylbenzene, or polytoluene is disclosed in United States Patent 5,510,156, which issued to Zhao on April 23, 1996, the disclosure of which is hereby incorporated by this reference in its entirety. If an elastomeric material is employed to fabricate conductive structures 24, the technique by which the thickness of solder mask 16 is reduced preferably does not substantially affect the configurations of the elastomeric conductive structures 24.

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[0043] FIG. 6 illustrates a conductive structure 24″ that tapers outward from the top portion thereof toward contact pad 14. As illustrated, the thickest portion of conductive structure 24″ is adjacent to contact pad 14, while the narrowest portion of conductive structure 24″ is the top thereof. The aperture 18 (*see* FIGs. 2-4B) within which conductive structure 24″ is formed may be defined through solder mask 16 by known processes, such as isotropic etching processes, that will provide an aperture 18 having a configuration complementary to that of conductive structure 24″.

[0044] FIG. 7 illustrates a conductive structure 24‴ with an upper portion 24a‴ having a transverse cross section taken along the height of upper portion 24a‴ of substantially uniform configuration. A lower portion 24b‴ of conductive structure 24‴ is located between contact pad 14 and upper portion 24a‴. The transverse cross section taken along the height of lower portion 24b‴ also has a substantially uniform configuration. Lower portion 24b‴ has a smaller transverse cross section than upper portion 24a‴. The aperture 18 (*see* FIGs. 2-4B) within which conductive structure 24b‴ is formed may be defined by disposing a photomask of the type

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disclosed in United States Patent 5,741,624, which issued to Jeng et al. on April 21, 1998, the disclosure of which is hereby incorporated in its entirety by this reference. Material of the solder mask 16 may then be removed by known etching processes through holes in the photomask to define stepped apertures 18 over contact pads 14.

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[0046] Of course, solder masks 16 having different shapes of apertures 18, as well as solder masks 16 having apertures 18 with combinations of different shapes, are also within the scope of the present invention. Accordingly, the present invention also includes semiconductor devices with combinations of different shapes of conductive structures on the contact pads thereof.